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OPERATIONAL MEMO NUMBER 3

NAVIGATION LABORATORY
AIR FORCE CAMBRIDGE RESEARCH CENTER

NAVIGATION LABORATORY PROGRAM AS OF 1 JULY 1956

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ABSTRACT

This memorandum outlines the Navigation Laboratory research and development program as of 1 July 1956. Some of the operational problems involved in the control of air traffic are described, together with the Laboratory's technical approach to the solution of these problems. The memo describes the creation of experimental control facilities and the investigation of some new electronic techniques, the status of their development, and the intended use of the resulting air traffic control equipments.

I N D E X

1.0 INTRODUCTION

Air traffic control problems are approaching this country with all the force of a revolution. If the USAF is to make effective use of its weapons systems---indeed, if aviation is to survive as a rapid means of transportation, a common all-weather system of control must be developed immediately.

In addition to developing equipments which will increase the USAF's capability to control its traffic overseas or in and out of secluded bases within the United States, it is necessary for the USAF to direct its efforts towards solving the problems of controlling its aircraft in high density traffic areas within the United States.

An air traffic control system must provide controllers with accurate and rapid data regarding the positions of the aircraft they are controlling. It must provide means for keeping track of the increased numbers of high speed aircraft, and means for automatizing the control process itself as much as possible.

The simultaneous control of mixed types of aircraft, with widely varying performance characteristics, requires automatic scheduling and automatic computation of safe flight paths. As a further explanation of the problem, it should be noted that the difficulties involved in controlling high density traffic do not increase linearly as a function of the number of planes, even if they are of the same type. As an example, 14 signals are not just twice as difficult to identify as 7 signals; it may be ten times as hard to discern who's who when there are 14 signals than when there are only 7. The probability of potential collision courses likewise increases at a non-linear rate.

Men, alone, cannot assimilate the vast amounts of data, compute precisely enough, or act fast enough to handle it. Equipment designed to handle any aspect of the problem, whether successful or not, will have its limitations, as men do. When the problems expand, the equipment also expands, along with the price, the number of operators needed to maintain and operate the equipment, etc. Each attempt at a solution must, of necessity, be a compromise on what is desired, to a certain degree. The primary requirement, not to be compromised, is of course safety.

Without the assistance of automatic control equipment, the rates of traffic movements can be expected to fall fantastically low, in order to maintain safe intervals. This will occur precisely at the time when more aircraft are available and in those places where most aircraft want or need to fly.

2.0 LABORATORY PROGRAM

The Navigation Laboratory at AFCRC is responsible for carrying out ARDC's research and development program in the field of air traffic control. The objective of this program is to increase the traffic rate and capacity of the USAF during the enroute, initial approach, and departure phases of flight operations.

The responsibilities are closely interrelated, revolving about different aspects of the air traffic control problem.

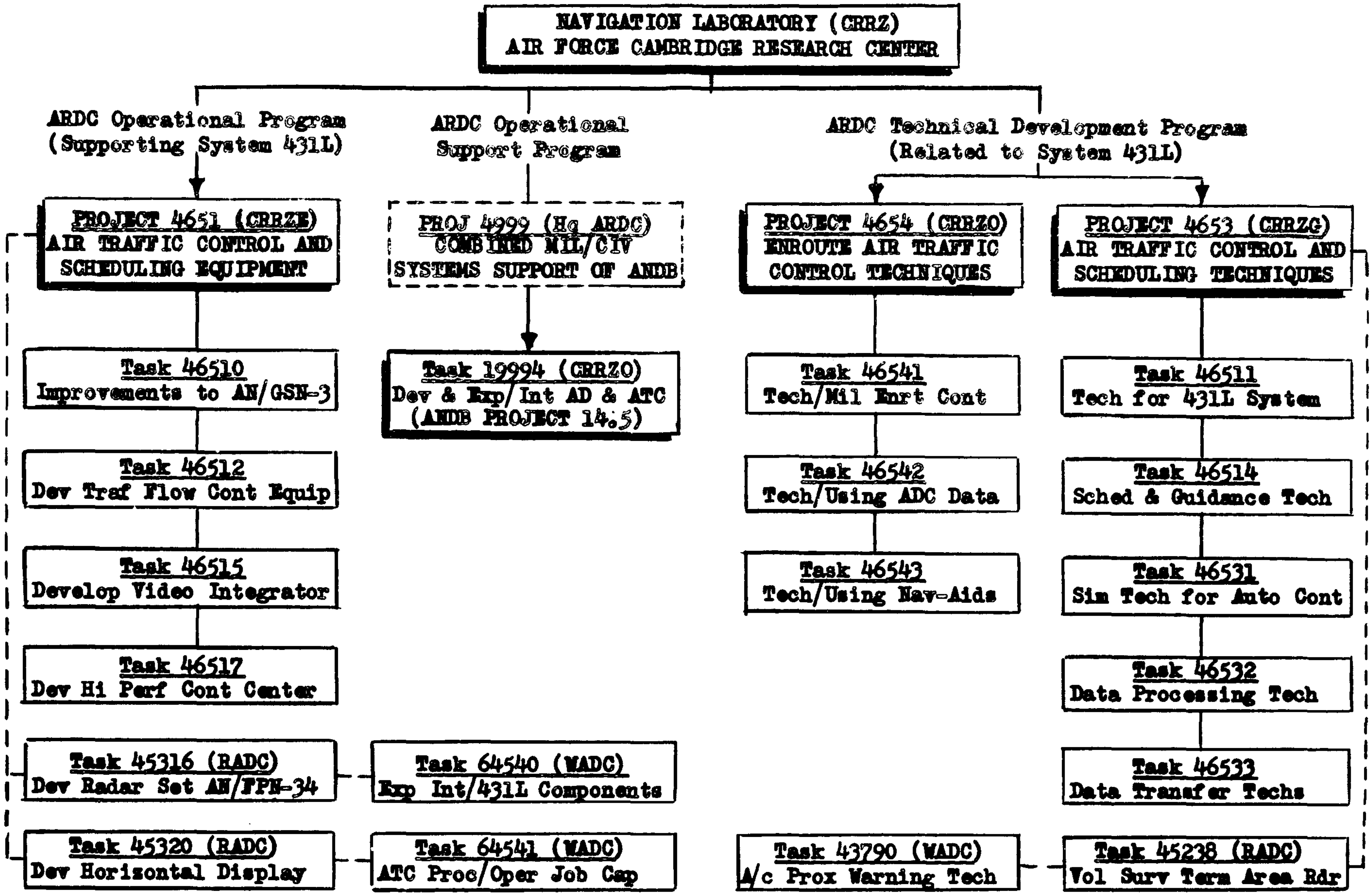
Under ARDC Project 4651 the Navigation Laboratory is developing the traffic control and scheduling equipment required for the ARDC 431L System, Traffic Control, Approach and Landing (TRACALS). This involves making specific improvements to existing equipments, developing related equipment, and specifying necessary operational procedures.

The Laboratory has a continuing research program to satisfy the more distant needs of the USAF. Under Project 4653 new techniques are being investigated which promise increased versatility, safety, and efficiency of control of aircraft scheduling and flight paths. Under ARDC Project 4654 the Laboratory is conducting R&D in enroute control, aimed at determining optimum equipment, configurations, and procedures for use by the USAF overseas.

In support of ANDB Project 14.5 the Laboratory is proceeding jointly with Civil Aeronautics Administration personnel to apply modern radar-computer techniques to expedite the civil and military air traffic within the United States.

Furthermore, the Laboratory is required to investigate what is needed in order for the control of aircraft to be rapidly transferred between TRACALS and other systems.

The Laboratory program includes all phases of activity——research, analysis of problem areas, technical development, design of prototype equipments, flight testing, and monitoring of research and production contracts.



2.1 Program Organization Chart

2.2 Background

The present Navigation Laboratory program represents a tremendous expansion of the work started under the old Volscan Project.

The original objective was to design an air traffic control radar which would provide a means for directing USAF aircraft back to their bases during all weather conditions. The first AN/CPN-18 radar, the (XD-1), was designed and built prior to 1946 and used as the data gathering device for a test of manual air traffic control performed during that year. Although the data gathered in this test was used primarily for the Volscan program, the (XD-1) itself was so successful that the Navigation Laboratory built three more at the request of ARDC; one for the All Weather Flying Center, one for Andrews AFB, and one for Westover AFB. These were the primary radar aids at these three bases for several years until production CPN-18's were made available. Later radar developments for air traffic control use have been carried on at Rome Air Development Center under Navigation Laboratory projects.

The AFCRC program was then directed towards a study of control techniques in order that USAF aircraft would have greater combat range and not have to conserve fuel for delays in the terminal area at low altitudes. This involved providing a means for controlling traffic rates of 120 aircraft per hour, rather than only 30 or 40, and for handling aircraft in emergency conditions. At the same time, the USAF placed a requirement for means of controlling mixed types of aircraft simultaneously. Automatic tracking-while-scanning (ANTRAC) and an automatic dynamic path computer (DATAC) were developed to provide the degree of precision needed for such traffic rates; a prototype model of these devices working together has since been known as Volscan. Tests in 1952 revealed that Volscan was capable of producing the needed precision.

The AFCRC Navigation Laboratory program objectives were then expanded to include the accomplishment of the above, but to more than one airfield simultaneously, and to include provisions for accepting aircraft at greater distances, higher altitudes, travelling at greater speeds, etc., and to provide this capability for more aircraft simultaneously, with no loss in accuracy. This resulted in specifications for the first AN/GSN-3 written in 1954.

Since that time the scope of the Laboratory program has continued to grow. The objectives now include all the above plus simultaneous control of departures and enroute traffic, such as might be present within the 120-mile radius of a busy terminal control center. Objectives now extend to such areas as the design of a flight plan computer which can clear aircraft along proposed flight paths prior to take-off, problems involved in accepting control of aircraft from various other control agencies, how to control aircraft in particular geographical areas with limited radar coverage or restricted airspace, etc. Each problem area includes multiple facets as briefly described in the following sections.

3.0 FACILITIES

3.1 TRACALS High Performance Control Center (HPCC)

PROBLEM: To determine optimum equipments, configurations, and procedures necessary for smooth control transition between TRACALS and other systems such as SAGE, TACS, BADGE, etc.

The environment in which an air traffic control system must function is not an isolated one. Aircraft must be transferred from the control of one ground-based system to another at a fast rate, commensurate with the various mission objectives, with no possibility of confusion of signals, mixup of flight data, or danger to the aircraft. Other aircraft may have to be transferred simultaneously from civil enroute centers such as a CAA Air Route Traffic Center.

This is not a simple problem for it involves very precise data regarding each aircraft and a high degree of coordination between agencies and controllers. Positional information must be in terms which are adequate for rapid identification of the aircraft signals by the system accepting control. Aircraft flight data must be transmitted in advance, ready for correlation with the corresponding aircraft signals. Direct ground-to-air communications must be established between the pilot and new controller, with radio channels coordinated to eliminate overloads and to insure that each pilot is directed to change to the correct channel when transfer is about to take place. At no instant of time can there be any question as to who is in control of the aircraft.

It should be noted that control transition will not occur in a vacuum; TRACALS operations will not be interrupted while aircraft are being transferred. Rather, control transition is foreseen as a continuous process, always taking place with outside agencies at one end or the other of an aircraft's passage through a TRACALS control area and continually occuring between operators of the TRACALS equipment within a TRACALS control center.

To evolve worthwhile solutions, the latest TRACALS equipment developments must be congregated and operated in a realistic ground environment. The configuration of these equipments within a control room will be determined by the adequacy of the arrangement for producing efficient control transition and by the basic control functions. Where possible, transition should occur between operators who are physically located next to each other in order to facilitate communications. These operators should be provided with a common video display which they can share, in addition to their separate ones, where necessary, for transferring of signal identification. Where the controllers are located at different agencies, at least one of them should be furnished with a video display similar to that which is available at the other agency. Provisions must be made by which

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departures can be safely meshed with inbound traffic, and by which a departing aircraft can reverse his direction and quickly be accepted by an inbound controller in case of engine trouble, etc.

The equipments and procedures evolved must not be limited in their application. That is, they must be flexible enough to allow for control transition during all weather conditions and be easily modifiable for use in different geographical locations. They must provide means for handling large numbers of aircraft simultaneously in the transfer stage, since an HPCC is expected to furnish a capacity for controlling at least 70 aircraft simultaneously. Transition must be rapid enough to insure that the TRACALS automatic control equipment will effectively produce inbound traffic rates of 120 aircraft per hour per runway.

APPROACH: The AFCRC Navigation Laboratory is creating a TRACALS High Performance Control Center (HPCC) at its Fort Dawes site in Boston, with the primary objective of finding out what is needed for aircraft to be rapidly transferred between systems. This is the only area in the United States where SAGE, TACS and BADGE missions are being experimentally flown today. The CAA ARTC for the New England area is located within three miles of the site. Aircraft movements in the vicinity of Boston provide a realistic high-density traffic environment.

Remoting links, some of unique design, will tie the HPCC to the USAF SAGE, TAC and Base Defense Systems and to the Boston ARTC. Telephone and teletype machines will be installed to handle data transmission. A PAR indicator, Kelvin-Hughes radar projector, and AN/UPA-35 universal indicators will serve as data displays (in addition to the two 16" and one 19" PPI's which are part of the AN/GSN-3). An MGR-2 final approach radar link for remoting data from Logan Airport is on order, and a 30" horizontal display being developed on contract by RADC is scheduled for installation upon delivery.

The latest developments in traffic control and scheduling equipment will be installed in the HPCC, including a Traffic Flow Group, an ATC Central AN/GSN-3(XD-1), Automatic Relay Group, Track Substitute Group, data link couplers, etc. The HPCC will receive its primary radar data from a modified AN/FPS-8. It will also be equipped with an AN/GRA-9 direction finder, AN/GPX-18 radar identification set, an MRR-4 radar relay remoting link, RAFAX recorder, UHF/VHF radio communications equipment, and an AN/FSA-4 communications central. Most of the above items are described in more detail in the following sections.

Army Engineers are constructing a new building of approximately 7000 square feet which will be used solely for the control room and its associated equipment. In the control room various physical arrangements

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of displays, scopes, automatic aids and control consoles are possible. Cable ducts will allow for experimentally testing different configurations. A conference-type arrangement of controllers would be preferable to an assembly line, but the number of operators who can be grouped around a single horizontal display is, of course, limited. Priorities will be assigned to their functions, some compromises reached, or new methods developed for handling control transfers between certain positions. The equipment configuration will be such that the HPCC can function manually, at a reduced rate, in the event of failure of the automatic equipment.

As a prerequisite of obtaining solutions, it is necessary to actually perform the transition process and determine the nature and extent of the problems. Equipment used for remoting and displaying video data will be tested for adequacy, and methods used for routing flight data such as by telephone, teletype and flight data strips will be replaced as soon as possible with a more rapid system of data transmission, capable of high capacity storage and automatic display of data when and where it is needed.

Initial HPCC flight experimentation will be with USAF and USN test aircraft, with commercial aircraft possibly participating in later stages of the testing.

Control of military aircraft will be transferred to the HPCC from the major weapons systems on an experimental basis upon completion of various test missions. The HPCC will then control the aircraft back to their respective bases, located within a 40-mile radius of the HPCC.

It is expected that control will be transferred from the combat systems to the HPCC while the aircraft are between 120 and 200 miles of the HPCC. Procedures and equipment will devised for controlling departures, such as military scrambles, in order to insure their safe passage through busy terminal areas regardless of weather conditions or the prevailing traffic situation.

INTENDED USE: All operations will be experimental in nature; it is not intended that the HPCC at Fort Dawes will provide any military or civil agencies with a traffic control capability on an operational basis. It is anticipated that the equipment installed and the control concepts used will change sub stantially as the HPCC flight experimentation program progresses.

In addition to its primary mission of evolving smooth transition, the HPCC will serve as the vehicle by which newly developed equipments can be scientifically tested in a realistic operational environment.

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The HPCC aims to achieve a substantially higher level of performance, both as to traffic rate and traffic capacity, than any other existing control center in the world.

The Navigation Laboratory intends to remote radar data from the final approach facilities at Logan International Airport in order that aircraft can be experimentally controlled through final approach and taxi from the HPCC. Aircraft to land at other fields will be turned over to the final approach facilities at those fields when they reach the final entry gates.

It is expected that analysis of HPCC operations will contribute greatly toward planning of the Common (Civil/Military) System.

STATUS: The new building for the TRACALS HPCC will be completed in the Spring of 1957. Installation of initial series of equipments will begin at that date, and operational tests of the initial configurations should begin in the Summer of 1957. All equipment for this phase is on hand or on order. Equipments of a more advanced nature will be programmed into the facility as soon as they are delivered from the contractors.

3.2 Experimental Enroute Control Center (EECC)

PROBLEM: The USAF requires a capability of controlling aircraft during the enroute phase of flight outside the Z.I. It must be possible to establish air routes overseas with capability of accepting flight plans, granting clearances, exercising flight control, integrating pilot reports with the output of data collection devices, avoiding collisions with random aircraft, etc. Traffic capacity and rates required are considerably higher than the CAA system now planned for the Z.I. The effective control of high altitude flights by jet aircraft is probably the most difficult aspect of the problem.

APPROACH: The Navigation Laboratory will establish at Fort Dawes a minimum ground environment for carrying out flight experimentation in the control of enroute traffic.

This facility will make use of those items in the TRACALS HPCC which are common to both enroute and terminal problems, i.e., voice communications, direction finding, data link, modified AN/FPS-8 radar, the High Quality Remoting Group, the MRR-4, simulators, Kelvin-Hughes displays, etc. The enroute facility will also include a number of separate components designed specifically to meet those characteristics of the enroute problem where the parameters differ widely from the terminal problem. This involves such items as automatic tracking-while-scanning, a Magnetronic Reservisor, a Flight Plan Extrapolator (MAMIE), etc.

INTENDED USE: This facility will permit the Navigation Laboratory to carry out scientifically controlled experiments on various aspects of the enroute problem; the quantitative data from these tests will provide a firm basis for specifying future enroute control equipment for the USAF.

STATUS: Building space for this facility is now available in T-22 at Fort Dawes. Although it will be possible to begin experimentation on a very limited scale during the Fall of 1956, the enroute facility is not expected to have any substantial capability until 1957.

4.0 DATA COLLECTION AND DISPLAY EQUIPMENT

4.1 Modified AN/FPS-8 Radar Set

PROBLEM: To obtain accurate and rapid positional data on all modern high performance aircraft within a 120-mile radius.

APPROACH: A standard AN/FPS-8 was obtained from AMC. A 75-foot steel tower was erected at Fort Dawes, and the AN/FPS-8 was mounted on it. General Electric Company was awarded a contract for a modification kit to increase the p.r.f. to approximately 600. A GPX-18 was obtained and installed to provide 200-mile coverage in all weather.

INTENDED USE: The AN/FPS-8 (modified) will be the basic radar data collection source for the TRACALS HPCC, the Experimental Enroute Control Center, and the Common System Experimentation Activity at Fort Dawes. The CAA will evaluate its coverage and will remote its data to the Boston Air Route Traffic Center if they find it acceptable. The radar will operate at 10 rpm.

STATUS: Unmodified AN/FPS-8 is now installed and ready for coverage tests. Modification kit is on hand and will be installed after unmodified set's coverage has been measured for later comparison.

4.2 Video Integrating Group

PROBLEM: To obtain strong and consistent signal returns on all aircraft within the coverage area of existing air traffic control radars, such as the AN/FPS-8 and AN/CPN-18. It is especially important to enhance and stabilize video signals if the controlled aircraft are to be automatically tracked. Since these radars are already in production and operational use, it is important that improvements be in the form of modification kits, rather than basic changes in radar design.

APPROACH: A video integrating circuit, which builds up all minimum-discernible signals until they are saturation-level signals, was designed by the AFCRC Navigation Laboratory and incorporated in an experimental modification kit which has been used successfully with the AN/CPN-18(XD-1) radar experimentally since 1952. For automatic tracking of jets, it is estimated this simple circuit increases the usable control range by about 33 per cent.

Three Video Integrating Groups, capable of enhancing the signals received from either AN/CPN-18 or AN/FPS-8 radars, are now being built on contract by the Airborne Instruments Laboratory. The Video Integrating Group substitutes a double-path MTI delay line for the radar's single-path line, uses one path for MTI and the new path for recirculating the video. Succeeding pulses from a target add together, thereby strengthening the received video. The Video Integrating Groups also include pulse length discriminators for assistance in rejecting interference prior to integration.

INTENDED USE: The three groups being built by A.I.L. will be used as follows: the first with Navigation Laboratory's AN/FPS-8 radar, one at WADC TRACALS facility, and one for service test at APG. The circuit can be easily modified to produce similar kits for any search radar, simply by changing the length of the delay line to correspond with the particular radar's p.r.f.

STATUS: Delivery is scheduled for FY-57.

4.3 High Quality Remoting Group

PROBLEM: To provide a TRACALS HPCC with video data processed by the SAGE computer. A picture of the positions of the tracked aircraft, with pertinent track numbers, is needed in the HPCC for rapid and safe control transition of aircraft returning to base from Air Defense missions and to determine the value of processed SAGE data for TRACALS and/or Common (Civil/Military) System use. A "quick fix" is needed so that flight experimentation can be carried out as soon as possible. Also progress is required towards an optimum means of tying the two systems together.

APPROACH: The AFCRC Navigation Laboratory has initiated two contracts concerned with the remoting of processed data from the Experimental SAGE Subsector to the Navigation Laboratory's HPCC and the Common System test facility at Fort Dawes.

As an immediate solution, General Electric Company is designing and fabricating a 2000-line closed-loop TV system. A television camera will be located at an area surveillance display in the SAGE control center at Bedford, Massachusetts; a wide-band forward-scatter microwave link will relay the data; and three 27" TV-type tubes will display it at appropriate locations in the Fort Dawes control facilities.

As a long range study, the Navigation Laboratory has a contract with Technitrol Engineering Company of Philadelphia aimed at producing a more optimum method of selective data transmission between SAGE and TRACALS control centers.

INTENDED USE: In line with present-day national policy, the long range objective is to utilize most effectively and economically the data already available within the Air Defense Command. SAGE data will be used during control transition from the SAGE weapons system to the HPCC, with HPCC operators identifying the aircraft signals by correlating their positions on the remoted SAGE display with their positions on a display of AN/FPS-8 radar data.

STATUS: The Navigation Laboratory has ordered, with R&D funds, one model of the High Quality Remoting Group. It is scheduled to be delivered in December 1956 and will be installed and placed in operation between the AN/FSQ-7 at Bedford and the HPCC at Fort Dawes in the Spring of 1957.

4.4 MRR-4 Remoting Link

PROBLEM: To obtain extended radar coverage for experimental flight tests.

APPROACH: An MRR-4 has been ordered from FY-56 funds and will be installed linking the ADC radar on Cape Cod with the HPCC, EECC, and CSRA.

INTENDED USE: To compare the remoted video with that obtained from the AN/FPS-8 at Fort Dawes, the High Quality Remoting Group [illegible] from SAGE, and remoted data from TACS-BADGE at Bedford, in order to evaluate the relative worth of these various data sources and types of remoting.

STATUS: Apparently funded in FY-56, but no definite negotiations in progres to date.

4.5 MGR-2 Remoting Link

PROBLEM: To provide final approach data from Logan Airport GCA to the HPCC to test integration of TRACALS traffic control with CAA final approach control.

APPROACH: To obtain an MGR-2 remoting link and install it between Logan Airport and Fort Dawes.

INTENDED USE: To supply data to a PAR indicator in the HPCC and carry out flight tests jointly with CAA on AN/GSN-3 feeding aircraft into Logan final approach.

STATUS: Funding scheduled for advance FY-57 service test.

4.6 AN/GRA-9 Direction Finder

PROBLEM: To locate the azimuth bearing of aircraft beyond the coverage pattern of the HPCC or EECC and steer them into it.

APPROACH: RADC is providing one model of the AN/GRA-9 to AFCRC Navigation Laboratory.

INTENDED USE: The AN/GRA-9 will be installed at Fort Dawes and its data remoted into the HPCC and EECC.

STATUS: Equipment delivery due in Summer of 1956. Installation in the Fall of 1956.

4.7 Radar Receiving System to Measure Elevation Angle

PROBLEM: To investigate a new and promising technique for obtaining height information simultaneously with range and azimuth data.

APPROACH: The AFCRC Navigation Laboratory initiated a purchase request for design of a radar receiving system in accordance with Navigation Laboratory performance specifications. The system will not include an antenna, but will be designed to operate from one which is similar to that described in AFCRC Antenna Laboratory Technical Memo No. 102, "A New Method for Obtaining Three Coordinate Radar Information" by C. Sletten. This antenna will provide two radar signals whose relative r-f phase will vary linearly as a function of elevation angle of the target aircraft.

The contract calls for the radar receiving system to accept r-f signals from two antenna terminals, measure the relative phase angle between the two signals (to an accuracy of one degree), and convert the measured phase difference into a video pulse output whose amplitude is proportional to the phase difference. The pulse will occur in time coincidence with the video pulse representing range and azimuth of the target.

The receiving system will not alter the relative phase angle of the received signals. It will be capable of operation with either radar or beacon signals, and will function with any radar whose pulse widths are within 0.5 - 3.0 microseconds. The system will include a self-checking circuit for automatically monitoring the accuracy of phase measurement and correcting for any drift that may occur.

INTENDED USE: The contractor is required to construct an experimental model of his design so that system performance can be demonstrated. For this test, the contractor will provide an L-band r-f signal generator which will generate the two phase-shifted pulse signals for injection into the front end of the receiving system.

STATUS: This FY-57 R&D contract has not yet been awarded.

4.8 Target Generators

PROBLEM: To provide controllable simulated aircraft signals for use in testing the accuracy, rate, and capacity of the new control devices which will be in the HPCC, the ERCC and CSRA.

APPROACH: Funds have been programmed in FY-56 service test for a 16-target simulator using digital techniques. It will have a range of 108 miles in increments of 0.1 of a mile and azimuth coverage through 360 degrees in increments of 0.33 degree. The targets will fade on tangential courses and in accordance with the earth's curvature. Target velocity is controllable from 0 to 2000 knots and forward velocity will be reduced if aircraft is climbing. Three layers of wind can be inserted independently.

INTENDED USE: This simulator will be installed in the HPCC, but will feed the other two experimental efforts also. The simulator can be manually controlled or programmed.

STATUS: Specifications were prepared by the Navigation Laboratory, and AMC is now negotiating a contract with the Newton Company of Manchester, Connecticut, for this equipment. Delivery is expected in the Spring of 1957. Service test funds have been requested in FY-58 to add another 16 targets, since the enroute problem will require this additional amount of simulated traffic.

4.9 Displays

PROBLEM: To adequately display the various types and pieces of data in the HPCC, EECC, and CSEA.

APPROACH: The Navigation Laboratory has initiated action to obtain the following displays:

(1) Eight (8) UPA-35 Indicators (from AMC)

(2) One (1) 30" Horizontal Display (from RADC)

(3) One (1) PAR Indicator (from FY-56 service test)

(4) Two (2) Kelvin-Hughes Projectors (from FY-56 service test)

(5) One (1) Multi-color PPI (from R&D funds)

INTENDED USE: These indicators will be used in the three experimental centers and/or efforts as needed. The primary objective of obtaining each is as follows:

(1) The basic radar displays of AN/FPS-8 data in the HPCC, EECC and CSEA.

(2) The main monitor display in the HPCC.

(3) To display the Logan PAR data in the HPCC

(4) To obtain large scale display for outer boundary of HPCC control area and for enroute control in the EECC.

(5) To provide an experimental display with targets color-coded in seven possible color combinations. Experimental tests will be run to determine advantage of using colors to represent such items as aircraft's altitude, destination, etc. Its application to various phases of flight will be evaluated.

STATUS: All items are on order. No delivery dates are available yet.

5.0 DATA ROUTING, COMPUTATION AND TRANSMISSION EQUIPMENT

5.1 Automatic Data Routing Group

PROBLEM: How to route and display aircraft flight data and how to communicate transfer messages rapidly and accurately enough to satisfy the needs of controllers handling large numbers of high-speed aircraft. It is known that existing methods of communicating information between operators (by flight data strips, yelling across the control room, or by teletype and telephone between control centers) will be inadequate, both as to speed and capacity for handling the high traffic rates expected in the future.

Adequate flight information must be available at the appropriate control position when needed. When control of an aircraft is passed from one operator to another, the accepting operator needs advance flight data in order to identify the aircraft signals and communicate with the pilot. He needs means for requesting a delay in the transfer if he is overloaded, a means for requesting a transfer when he is ready, and means for accepting control responsibility when identification and radio contact has been made with the pilot. Permanent data records must be maintained.

APPROACH: The AFCRC Navigation Laboratory specified the operational requirements for an Automatic Data Routing Group now being designed on contract by Cook Research Laboratories.

The requirements call for keyboards and data display boards to be furnished all HPCC controllers and also all operators located at the other system centers involved in control transition of the aircraft, such as SAGE, TAC, and CAA ARTC centers, with a central storage drum located in the TRACALS HPCC.

In addition to accepting, routing, and displaying pertinent flight data at the proper place at the proper time, the design will provide means by which the operators can rapidly communicate the necessary transfer messages to each other and means by which each one, in turn, can accept responsibility for control of the aircraft. These messages will be displayed on the data boards on a line with the data of aircraft concerned. Data requirements were specified for both inbound and outbound aircraft, with specifications for automatically notifying the HPCC Operations Supervisor of the traffic workload at each position at all times.

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INTENDED USE: While the Automatic Data Routing Group is being designed to satisfy the needs of the Navigation Laboratory's HPCC, it should be flexible enough to satisfy the needs of other TRACALS HPCC's. It may not be feasible to expect that all the detailed specs will be met or that it will be practical to build a single equipment with capacity enough to meet all the needs of various TRACALS centers. The present design contract will directly result in a contract for a prototype Automatic Data Routing Group. If successful, similar equipments will have wide application.

STATUS: The design work is being funded from the R&D program and will be completed in the Spring of 1957. FY-58 funds have been requested for a service test model.

5.2 Traffic Flow Group

PROBLEM: To regulate the flow of air traffic into a terminal area so that too many aircraft will not arrive all at once, requiring simultaneous identification and causing an overload of the system in use within the terminal area; to provide early warning of anticipated traffic peaks in order that any long delays may be taken while the aircraft are still at high cruising altitudes and outside the more congested precise-control area; and to keep track of the aircraft so directed.

APPROACH: The AFCRC Navigation Laboratory has designed an electronic aid which automatically uses the output of automatic tracking to produce a clock-type traffic flow display for the controller's use. The Traffic Flow Group provides a controller with the capability for automatically tracking aircraft within a 200-mile radius of the radar and with a means for observing the predicted rate at which the tracked aircraft will arrive at a certain range. Its tracking channels automatically feed circuitry which causes the time-to-go of each tracked aircraft to be displayed as a pulse position on the periphery of the controller's PPI. From this "time" display, a controller can easily judge when time delays are necessary. A light gun is used to correlate the time-blips with the tracking gates assigned to the various aircraft.

INTENDED USE: In the TRACAL System, aircraft located within 200 miles of the HPCC will be directed toward the AN/GSN-3's control area by a traffic flow controller until the automatic terminal system accepts them. Centers not equipped with an AN/GSN-3 would find the equipment a valuable semi-automatic control aid.

STATUS: Components have been breadboarded and tested by the Navigation Laboratory. A specification has been prepared and FY-57 funds requested for three service test models: one for the HPCC at Fort Dawes, one for the TRACALS facility at WPAFB, and one for APGC.

5.3 Collision Prediction Unit

PROBLEM: To predict each aircraft's future position in space, compare it with the future positions of all other controlled aircraft, and warn an operator when the positions of two or more aircraft are due to coincide in time. An aircraft's static position in space can be considered to have three dimensions, its range and its azimuth from a ground control center and its height from the ground beneath it. When time is added to the problem and a prediction must be made, it is known that the aircraft's range and azimuth will change and that his height may change. The amounts of change in these three dimensions are determined by the aircraft's true airspeed, its heading (and the number of degrees per second and direction it will turn, if it does), its altitude, and rate of descent or ascent if changing.

These factors are determined by the aircraft's performance characteristics, the pilots actions, the velocity and direction of the wind and the air density at the various altitudes. A prediction of an aircraft's true future position can be made only if all these factors are known or can be controlled.

APPROACH: If it is certain that, in a given situation, all controlled aircraft will continue on their present headings at their present velocities (i.e., assuming the pilots are told to do this by a ground controller), a reasonable prediction and comparison of their future positions can be made automatically.

The AFCRC Navigation Laboratory has initiated a purchase request for a collision prediction unit which will do this in range and azimuth only.

Using the output of existing analogue trackers and using known analogue computing techniques, the unit will make a linear extrapolation of each aircraft's present heading and velocity as stored in the memory circuit of each tracker. It will compare each predicted path with every other predicted path and activate warning signals when two or more aircraft are on paths which will coincide in range and azimuth at the same time. A controller will then take action to avoid the situation if his knowledge of the altitudes of the aircraft involved indicates there is danger of a real collision.

INTENDED USE: This device will be limited to predicting positions of aircraft which are being tracked and which are being controlled in a straight line without change of airspeed and without radical change in altitude. Its warning signals should assist a controller such as the HPCC Traffic Flow Controller. It is not intended that the device assist a monitor of aircraft being controlled by the AN/GSN-3 which directs aircraft to fly curved paths while descending at perhaps 4000 feet per minute.

STATUS: The FY-57 contract has not yet been awarded. The R&D model will be operationally tested in the HPCC.

5.4 Air Traffic Control Central AN/GSN-3(XD-1)

PROBLEM: To control mixed-type aircraft in a busy terminal area in such a way as to produce an airfield delivery rate of 120 aircraft per hour. Such control includes the following problems:

1) How to keep track of many aircraft simultaneously regardless of the direction from which they come, and accurately predict the time it will take for each aircraft to reach its destination, taking into consideration such factors as the wind velocity and direction and changes in air density caused by the aircraft's descent, as well as their various airspeeds and changes in airspeed as the aircraft proceeds from cruise to final velocity.

2) To rapidly select a safe time of arrival for each aircraft, one that it can make and one which is not in conflict with other traffic.

3) To figure what headings the aircraft should take, when it should start its descent, lower its gear and make a final cockpit check, in order that it will arrive on schedule with split-second precision despite any minor inaccuracies in aircraft instruments, pilot errors, or temporary radar failures.

APPROACH: The AFCRC Navigation Laboratory designed an Air Traffic Control Central AN/GSN-3 which automatically tracks 14 aircraft signals simultaneously, schedules their delivery times, and issues control instructions so they will arrive on schedule. The AN/GSN-3 will accept data inputs from any primary or secondary radar and produce control orders which can be relayed manually or automatically over conventional UHF/VHF radio, or via data link, to the pilots, thus forming a closed-loop system. After manual assignment, the AN/GSN-3 retains the identity of the aircraft targets, selects the earliest possible delivery schedule which each aircraft can meet without conflict with other traffic schedules and automatically orders offset headings as necessary to pinpoint each aircraft's arrival time at the desired final approach entry gate or touchdown point.

Three Articles of the AN/GSN-3(XD-1) are being built by Crosley Division of AVCO Manufacturing Corporation in accordance with Navigation Laboratory specifications. The AN/GSN-3(XD-1) is more flexible and efficient than the prototype Volscan equipment due to Navigation Laboratory improvements developed since the Volscan Field Test in 1952.

With the AN/GSN-3(XD-1) it will be possible to automatically schedule aircraft to touchdown rather than only to final approach entry gates. Flight path computation will take into consideration each

(5.4 continued...)

aircraft's rate of turn, allowing a wider turn circle for jets than for props. The tracking channels will automatically control the gain of tracked beacon signals, individually suppressing any extended side lobes such as ring arounds, and they will accept their video inputs individually, allowing selection of the optimum signal on any given aircraft.

To achieve the desired traffic rates and meet Navigation Laboratory specs, 95% of the controlled aircraft must arrive at the entry point within plus or minus 9 seconds of their scheduled arrival times.

INTENDED USE: The three Articles of the AN/GSN-3(XD-1) are to be used as follows: The first will be installed in the TRACALS HPCC at Fort Dawes, the second will be delivered to APGC in February 1957, and the third to WADC in March 1957.

It should be noted that the number of channels and operators required for future AN/GSN-3 operational use is dependent upon the desired rate of delivery and the density of the expected traffic. For example, 7 channels and 4 operators can produce a sustained traffic rate of 60 aircraft per hour, or 14 channels and 7 operators a rate of 120 per hour.

STATUS: Seven channels of the First Article AN/GSN-3(XD-1) are now undergoing component testing at the Navigation Laboratory site in Boston, Massachusetts. The complete 14-channel First Article will undergo an approval test at Clinton County Air Force Base in Ohio during the Fall of 1956 under the direction of Navigation Laboratory personnel.

5.5 Air Traffic Control Central AN/GSN-3(XD-2)

PROBLEM: To provide an air traffic control computer with greater flexibility and safety than the AN/GSN-3(XD-1) and to reduce the number of operating personnel required.

APPROACH: The Navigation Laboratory has been studying means of improving the AN/GSN-3 and is now ready to incorporate various improvements in a new model. Although its basic philosophy is unchanged from the AN/GSN-3(XD-1), the performance of the (XD-2) will be more efficient in terms of aircraft per controller.

Among the new features to be incorporated are the Automatic Relay Group, a coupler for the GKA-5 data link, flexible height programming, completely independent scheduling for six airports, automatic spacial separation, automatic velocity correlation between aircraft and computer, and increased accuracy of scheduling.

INTENDED USE: Two models will be obtained from FY-57 service test funds. One will be installed in the TRACALS High Performance Control Center at Fort Dawes, with the second to be delivered to the TRACALS facility at WADC.

STATUS: Specifications are in the initial stages of preparation and will be ready by January 1957.

5.6 Automatic Maintenance of the AN/GSN-3

PROBLEM: To make the AN/GSN-3 more fail-safe by providing it with means for automatically detecting and indicating its own malfunctions.

APPROACH: The AFCRC Navigation Laboratory has a contract with Crosley Division for design and construction of a prototype automatic maintenance system for the AN/GSN-3(XD-1). This system will automatically monitor the waveforms and take advantage of other means to check conformity of component operations, and as a result will provide indication of any malfunctions by way of warning lights and meters at an automatic-maintenance desk.

INTENDED USE: This is a design study only. It will contribute toward the design of the AN/GSN-3(XD-2).

5.7 Miniaturization of the AN/GSN-3

PROBLEM: To reduce the total volume and power requirements of the AN/GSN-3 so that it will require less space for operational use and be more economical and practical for use where needed.

APPROACH: The Navigation Laboratory has an R&D contract with Crosley Division of AVCO for a study of miniaturization of AN/GSN-3 components in general. It should be possible to substantially reduce AN/GSN-3 requirements by employing new packaging techniques and miniaturization.

INTENDED USE: The results of this study will be incorporated in later models of the AN/GSN-3(XD-1) and in the AN/GSN-3(XD-2).

5.8 Automatic Voice Relay Group

PROBLEM: To notify the pilots of computer-derived control orders immediately and accurately; to eliminate possibility of human errors caused by fatigue from the monotonous task of manually relaying instructions by radio as they appear on ground-based heading indicators and brightened indicator lamps; to provide standardization of AN/GSN-3 control messages; and to decrease the number of operators and radio communications channels needed for AN/GSN-3 operation.

APPROACH: The AFCRC Navigation Laboratory initiated a contract with Cook Research Laboratories for design and fabrication of a 15-channel automatic voice relay device. This equipment utilizes voice recordings, on a magnetic drum, of the eighty-five AN/GSN-3 control orders, and automatically transmits the appropriate messages to the pilots at the proper times. The equipment has a built-in priority system with provisions for immediately contacting aircraft which are in an emergency condition and for giving instructions at a maximum rate to aircraft which are nearing their destinations where accuracy requirements are greatest.

The Automatic Voice Relay Group will allow the four relay operators to be replaced by a single relay monitor and will decrease the communications requirements from four to three conventional UHF/VHF radio frequencies. Each radio channel will be tied in with five computer channels; instructions will automatically be transmitted on the appropriate frequency with each aircraft vocally addressed by its AN/GSN-3 channel designation such as "ALPHA-THREE".

INTENDED USE: This method of getting control instructions up to the pilots has attracted considerable attention among many military and civilian agencies for the reason that it automatizes the relay process without requiring any additional equipment in the airplane, such as data link requires.

The prototype model will be integrated with the AN/GSN-3(XD-1) and be subjected to experimental flight testing under the direction of Navigation Laboratory personnel. No service test model is scheduled since this device will become an integral part of the AN/GSN-3(XD-2).

STATUS: Delivery of the R&D model from Cook is expected in August of 1956.

5.9 Track Substitute Group

PROBLEM: The An/GSN-3 computer may issue an inaccurate heading instruction to an aircraft due to temporary fading of its radar signal during a turn. If this occurs when the aircraft is near the end of its initial approach, the aircraft may have to make a go-around; if it is still far out in range, manual reassignment of tracking or rescheduling may be required.

Although the AN/GSN-3 is usually able to correct the error automatically, it would be preferrable to prevent its occurence. At present, the AN/GSN-3 automatic tracking is designed to continue tracking on "memory" during a fade, feeding the computer a linear extrapolation of the aircraft's heading at the time of its last radar return. If the aircraft radically changes its heading during the fade, the computer temporarily receives incorrect positional information on the aircraft (and its heading instructions are based on this positional data). Unfortunately, a signal may fade precisely because the aircraft changed its heading, causing a change in its attitude with relation to the radar which may temporarily offer less of a reflective surface.

APPROACH: The AFCRC Navigation Laboratory has a contract with the Newton Company of Manchester, Conn., for design and fabrication of a Track Substitute Group in accordance with Navigation Laboratory performance specifications. This device will provide the automatic trackers with a dynamic substitute target when the real signal fades. The substitute target will automatically follow AN/GSN-3 computer instructions issued for that aircraft, in both heading and velocity, and will turn at the same rate as the real aircraft.

The computer will receive data based on the position of the substitute target rather than a linear extrapolation of the real aircraft's last known heading. The Track Substitute Group will increase the probability that the tracking gate will be centered on its target when the real signal reappears, that the computer will continue to receive accurate positional data, and that the AN/GSN-3 will continue to issue correct heading instructions despite temporary fading of the aircraft signal.

INTENDED USE: The Track Substitute Group being built by Newton Company is a single-channel device for experimental use with the AN/GSN-3(XD-1). If successful, a multi-channel one will be incorporated in the AN/GSN-3(XD-2). As designed, it will have no application for use with automatic tracking only; its use is tied in with an automatic dynamic-path computer such as the AN/GSN-3.

STATUS: Delivery of the R&D model is expected in the Fall of 1956.

5.10 Data Link Couplers

PROBLEM: To couple the outputs of the AN/GSW-3 to the USAF data link for automatic remoting of control orders from computer to aircraft.

APPROACH:

(1) A GKA-3 coupler has been designed at Navigation Laboratory and is being fabricated locally.

(2) A GKA-5 coupler will be designed on contract using FY-57 R&D funds.

(3) A GKA-3 ground station will be obtained through 431L System Office.

INTENDED USE: The couplers will be used during experimental flight tests to measure accuracy of control and suitability to 431L System needs and to evolve acceptable control room techniques for taking maximum advantage of the data link capability.

STATUS: The GKA-3 equipment and coupler will be ready in the Fall of 1956; the GKA-5 coupler delivery date is not available yet.

5.11 Flight Plan Extrapolator (MAMIE)

PROBLEM: BADGE (Base Defense System) has requested TRACALS to supply them with extrapolated flight plan data on all friendly aircraft operating in a BADGE area overseas.

APPROACH: The Navigation Laboratory is studying how to provide automatic equipment to meet this problem. Because of the large numbers of targets involved, mechanization is essential. The machine will accept flight plan data and will generate a symbol on a display representing the predicted position of the target and the quality of the data (i.e., how long it has been since there has been reliable data on the actual position of the target).

INTENDED USE: A single model of this equipment will be installed at Fort Dawes with the data remoted to the BADGE system at Bedford, Mass.

STATUS: A design study and fabrication of one model will be funded from R&D sources as soon as money is available.

5.12 Magnetronic Reservisor

PROBLEM: To determine whether or not an aircraft will be in danger of colliding with other traffic if he flies his proposed flight plan. To determine a safe alternate flight plan in case of predicted conflict on the original plan; to intermittently or continually recheck flight plans in the light of new data; and to check for conflicts caused by aircraft instrument errors, wind, weather, aircraft condition, etc., after take-off. Present methods in use are slow and subject to human computation errors.

APPROACH: The AFCRC Navigation Laboratory specified general performance requirements for a Magnetronic Reservisor to be designed and built by Teleregister Corporation for use in Fort Dawes enroute control experimentation.

Upon insertion of a route card and depression of appropriate flight data keys, indicator lights will brighten, green for clear or red for conflict, corresponding to each leg of the route. When a conflict appears, alternative flight data keys will be manually depressed or a different route card manually inserted until the flight plan produces only green lights. The Magnetronic Reservisor will not automatically select an alternative take-off time, altitude, or route, but it will be capable of checking for potential conflicts between aircraft along 20 airways with a maximum of 16 legs and at different altitudes (in thousand-foot increments).

INTENDED USE: Using actual flight plans filed with the Boston Air Route Traffic Center, Navigation Laboratory personnel will evaluate the Magnetronic Reservisor for accuracy and speed in computing flight path conflictions.

STATUS: FY-56 service test funds have been programmed for one model, and AMC is now negotiating for a contract based upon an exhibit prepared by the Navigation Laboratory.

6.0 SERVICES

6.1 Analysis of Techniques Applicable to TRACALS

PROBLEM: To insure that new techniques are adequately analyzed to determine their potential application to TRACALS. Techniques that have potential use in the field of air traffic control and landing may originate as the result of effort in an entirely different field. This information therefore must be gathered and sifted from a wide variety of sources.

APPROACH: The AFCRC Navigation Laboratory has a broad study contract with Stavid Engineering, Inc., of Plainfield, New Jersey, under which Stavid engineers are required to investigate promising techniques that may be pertinent to certain assigned problem areas. The technical and/or operational problems are described in detail by Navigation Laboratory scientists, with priorities assigned and information sources suggested or required. Stavid engineers visit the recommended sources, review pertinent reports, and draft conclusions jointly with the AFCRC scientists.

As a result of their first assignment, Stavid surveyed and evaluated target generators and associated equipments which may be used for simulation tests of the AN/GSN-3. Of their current assignments only two are unclassified: 1) investigation of techniques for suppression of side lobe returns of secondary radar such as beam splitting techniques and automatic gain tracking, which may produce more precise and stable beacon returns for air traffic control use; and 2) investigation of large-scale projection-type displays, CRT displays giving both pictorial and symbolic information, techniques for displaying height information, and special type displays.

INTENDED USE: The end products of this contract are recommendations to the TRACAL System Team. The joint conclusions may thereby have a direct effect on the planning of future equipments included in the 431L System and may eliminate unnecessary duplication of R&D effort. A library of up-to-date reports, bibliographies, and abstracts of pertinent reference data relative to existing equipments and current R&D at other agencies, forms an important by-product of this contract, available for use by interested scientists.

STATUS: The contract using FY-55 funds expires 1 Sep 56; a new contract using FY-57 funds has been initiated to provide a continuation of this work by Stavid.

7.0 COMMON SYSTEM EXPERIMENTATION ACTIVITY (CSEA)

PROBLEM: To contribute towards improving air traffic control within the Z.I.

APPROACH: To provide a capability for, and carry out, flight experimentation directed towards improved data gathering, automatized storage and distribution of data, automatized extrapolation of data, and improved display.

The Experimental Enroute Control Center and the TRACALS High Performance Control Center will provide almost all of the facilities and equipment for this work. Equipment will be designed and fabricated for this activity only when such an approach has been specifically requested by the ANDB and is funded by that agency. The problem of effectively integrating TRACALS and Air Defense equipment and techniques into the Common System is a major portion of this work.

INTENDED USE: Flight experimentation on the Common System will be planned and carried out jointly by military and civil personnel representing USAF, USN, ANDB, and CAA.

STATUS: Studies and planning are now in progress. Flight experimentation will proceed in parallel with and at a rate consistent with similar work in the HPCC and the Experimental Enroute Control Center.

7.1 CSEA Test Program

PROBLEM: To plan a program of experimental flight tests which will yield the information necessary for determining the critical design parameters of new equipments for the Common (Civil/Military) System. The nature of this problem requires a Gestalt approach which will take into account the entwined requirements, capabilities and status of air traffic and of control systems such as the Airway Control System, SAGE, TRACALS, etc., during a future time period.

APPROACH: The Navigation Laboratory initiated three contracts with ANDB funds, calling for three companies to participate with the Laboratory in planning a major aspect of the Common System Experimental Activity at Fort Dawes. The companies are Airborne Instruments Laboratories, International Business Machines Corp., and Union Switch and Signal Company. They will investigate the functions of an integrated Common System of air traffic control, and will recommend specific flight tests which will define the parameters of new equipments to be developed which will improve the performance of the system.

Work under the contracts will be divided into phases of approximately one month's duration, with each phase dedicated to the study of a particular critical problem area, such as data collection, tracking, computation and control, or communications. At least two meetings per phase will be held at the Navigation Laboratory, with all three companies represented, in order to insure that maximum coordination and interchange of data takes place on the three efforts.

The three companies each have a background of valuable experience directly relating to the problems to be solved. For example, A.I.L. is presently under contract with Brig. Gen. Curtis, Special Assistant to the President of the U.S., to investigate the U.S. air traffic workload expected during the period 1960-1970. I.B.M. has been the principal contractor of the USAF in the design and development of the AN/FSQ-7 SAGE computer. Union Switch and Signal has recently completed a study at the CAA Technical Development and Evaluation Center in Indianapolis regarding the routing of airway control data within a CAA center.

INTENDED USE: Each contractor will draw up conclusions for each phase, representing the best analysis the contractor can make, on a theoretical basis, of the degree to which integration is practical in the selected problem areas during the years 1960-1970. They will make recommendations proposing a specific practical test which can be carried out prior to 1960 to demonstrate the validity of each conclusion.

STATUS: These FY-56 contracts have not yet been negotiated; all three will start on the same date.

7.2 CSEA Test Design, Data Collection and Analysis

PROBLEM: To obtain the engineering services needed to design tests which will provide meaningful data regarding the operation of equipment for the Common System. To collect and statistically analyze the test data.

APPROACH: The AFCRC Navigation Laboratory has initiated a contract to obtain the services of Franklin Institute personnel who have technical and operational experience in air traffic control and a comprehensive knowledge of ANDB objectives. Their contribution will be a logical extension of their recent study of operations at the Boston ARTC and experiments underway at TDEC in Indianapolis.

INTENDED USE: It is expected that Franklin Institute will participate with Navigation Laboratory and CAA personnel in the detailed planning of tests and in defining test criteria. In addition, Franklin Institute will be solely responsible for providing the services and materials necessary for data collection and statistical analysis of the test data.

STATUS: The FY-57 contract has not yet been negotiated, but the Navigation Laboratory has requested that work begin as soon as possible after 1 July 1956 and no later than two weeks after the contract is awarded.